

Comparative study of different means of concentrated solar flux measurement of solar parabolic dish



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ARTICLE INFO

Article history:

Received 10 April 2013

Accepted 31 August 2013

Keywords:

Solar heat exchanger
Concentrated solar radiation
Exergy efficiency
Concentration factor
Energy efficiency

ABSTRACT

The purpose of this work is to evaluate the energy coming to the focus of a solar parabolic concentrator SPC using four types of absorbers: flat plate, disk, water calorimeter (WC) and solar heat exchanger (SHE), developed in the Research and Technologies Centre of Energy in Borj Cedria in Tunisia (CRTE). The temperature of the absorber, the solar energy absorbed by the receiver, the mean concentration ratio and both energy and exergy efficiency of the system were obtained experimentally. In order to validate the experimental results of the SHE and to determine the SPC efficiency using the disk, an analytical study based on thermodynamics analysis is carried out. We note that a good agreement between the four experimental methods has been obtained with the four receivers used in this work. The thermal energy efficiency varies from 40% to 77%, the concentrating system reaches an average exergy efficiency of 50% and a concentration factor around 178.

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1. Introduction

The world energy demand is projected to be doubled by 2050 and will be tripled by the end of the century [1]. The actual classic types of energy will not be capable to supply this demand in a sustainable way. Many countries have been directed to the use of renewable energies resources as a promising alternative for their energy need. Tunisia has an important solar energy potential with an annual average global solar radiation exceeding 2000 kW h/m²/year [2]. Many scientific researches in Tunisia are oriented to the solar energy. Recently, medium–high temperature applications are an important topic in the solar energy sector. Private and Tunisian public firms have signed contracts of 450 million euro with international institutions for the implantation of new solar concentrating installations in the south of Tunisia. The energy provided by the solar systems (evaluated in 72.6 ktep/year) and the total power installed will reach a capacity of 290 MW [3].

Many solar concentrator applications and projects exist in the world. Wua et al. [4] evaluated the thermal–electric conversion performance of parabolic dish/AMTEC solar thermal power system. The overall conversion efficiency of the system could reach 20.6% with an output power of 18.54 kW. Blanco et al. [5] described “Solar detoxification technology in the treatment of persistent non-biodegradable chlorinated industrial water contaminants” project, in order to develop a commercial solar water treatment technology

based on compound parabolic collectors (CPC). Kleih [6] realized a test facility for parabolic dish systems with sterling motor in their focus. Performance ranges from 5 to 25 kWel (depending on concentrator geometry, insolation, and engine). This author described the video-camera measuring system HIMAP used in this work to qualify concentrating modules within the test facility. Nuwayhid et al. [7] described a simple solar tracking concentrator realized and tested. They concluded that the total cost of a solar concentrator using available components is not more than 58.57 \$/W and the power concentrated of the concentrator is about 5.9 W/m². A comparative thermal performance study of three parabolic concentrators under Malaysian environment has been done by Rafeeu and Kadira [8].

Solar cooking is a simple application of solar parabolic concentrator. However, there are several designs for various types of solar cookers. Balzar et al. [9] tested a solar cooking system using vacuum-tube collectors with integrated heat pipes under cold and hot conditions. Grupp et al. [10] presented a synopsis user meter for two solar cooker models (SunStove boxes and K10 concentrators), the metering device is an automatic recording and evaluation tool to determine use frequency, thermal mass of cooked food and cooking time. Muthusivagami et al. [11] presented a new concept of PCM-based storage type solar cooker and they reviewed many researches of solar cookers classified with and without thermal storage. Badran et al. [12] designed a portable solar cooker water heater; the collector component was modified in shape, dimensions and inner construction of the absorber plate. Also the cooker component was more investigated by adding glazing around the

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power of a point focus concentrator system named DEFRAC. They developed a CFD code for CAVICAL calorimeter. Other geometry of calorimeter (a flat-plate calorimeter) was settled up by Jaramillo et al. to evaluate measuring concentrated solar flux. They have shown that the radiative losses can be neglected in the thermal balance of the system [25,26].

The aim of this work is to determine the solar energy absorbed by the receiver of the SPC concentrator and to quantify the global heat losses to the environment as well as to establish the validity of the experiment for the system using different means of measurement. In this work there are two types of heater exchanger: solar heat exchanger and water calorimeter placed at the focus of a mobile parabolic dish SPC which were designed and implemented in Research and Technologies Centre of Energy in Borj Cedria in Tunisia (CRTEn). We will describe in Section 2, the methods used for measurement of a high solar irradiance. In Section 3, a thermodynamic study of energy and exergy efficiency is carried out to evaluate the system efficiency. In Section 4, we will describe the experimental setup. In Section 5, we will report the experimental and analytical results. The main remarks of this work will be reported in the conclusion.

2. Methods used for measurement of high solar irradiance

2.1. Thin plate method

Thin plate method is based on the sudden change of temperature in unsteady mode. This experimental method used as a receiver, a circular copper thin plate with 12 cm of diameter weighting 153.78 g. The temperature of the thin plate measured with a thermocouple placed at the plate center was channeled through grooves.

The heat equation in a thin plate is written as follows:

$$mC_p \frac{dT}{dt} = Q_u + Q_a - Q_{p-cv} - Q_{p-r} \quad (1)$$

where Q_u , Q_a , Q_{p-cv} and Q_{p-r} are the useful concentrated solar flux, the absorbed flux, the heat losses by convection and the heat losses by radiation, respectively.

Hypotheses used in this part are the heat losses by convection and radiation are neglected because at time ($t = 0$), the plate temperature is equal to ambient therefore the Eq. (1) can be written as:

$$mC_p \left(\frac{dT}{dt} \right)_{(t=0)} = Q_u \quad (2)$$

$a = \left(\frac{dT}{dt} \right)_{(t=0)}$ is the slope in the beginning of the temporary plate temperature variation and C_p is the heat capacity. At time $t = 0$, the thin plate temperature varies linearly according to the time so to determine concentrated flux it is necessary to determine the slope in the beginning.

$$T = at + T_a \quad (3)$$

where T is the thin plate temperature and T_a is the ambient temperature.

2.2. Disk method

The disk method is based on the determination of solar concentrated energy using the energy balance. 5 type – K-thermocouples (with $\pm 0.5^\circ\text{C}$ accuracy) placed in the internal face of the disk at 0.005 m of depth. In Table 1 the radial locations of these thermocouples are reported. Two thermocouples are used for each symmetric radial position. The useful thermal power Q_u can be determined by.

$$Q_u = Q_a - Q_p \quad (4)$$

Table 1

Characteristics of the disk.

Material of the disk: stainless Think of the disk: 0.01 m		
Diameter of the disk: 0.012 m		
Position in the disk	Symbol of the position	Distance from the center of the disk, m
Position 1	P1	0.05
Position 2	P2	0.025
Position 3	P3	0
Position 4	P4	0.025
Position 5	P5	0.05

where Q_a , Q_p , Q_{p-cd} and Q_{p-cv} are the solar energy absorbed by the receiver of solar parabolic dish system, heat losses from a receiver, conductive, convective and radiative losses, respectively.

2.3. Water calorimeter

A water calorimeter is a solar concentrated energy evaluation device placed at the SPC focus where the used heat transfer fluid is the water. This calorimeter made of steel is constituted of two concentric cylindrical conduits, two plates and two rings. The circular steel receiving plate (1) collects the concentrated solar radiation (with 3 mm of think). The distributing plate (2) is capable to distribute water inside the calorimeter. The sealing ring (3) prevents any contact between the outlet and inlet fluid. The polyamide ring (4) covers all the inferior part of the body of the calorimeter to prevent any contact between the various components of the absorber and to minimize heat exchange between the water and the body of the calorimeter. The heat flux Q_u extracted by the calorimeter is expressed as:

$$Q_u = \dot{m}_w C_{pw} (T_{outlet} - T_{inlet}) \quad (5)$$

where $\dot{m}_w$ is the mass flow rate of water, C_{pw} is the water heat capacity, and $(T_{outlet} - T_{inlet})$ is the temperature difference between inlet and outlet water.

2.4. Solar heat exchanger

The solar heat exchanger is a tube exchanger. It consists of three main components: spherical cavity, exchanger body and the back cover. The body of the exchanger is a solid cylinder of 140 mm opening diameter and 240 mm length, pierced by 52 holes with a 10 mm diameter. These holes form tubes, grooves are placed between every pair of tubes which form a continuous throughout the exchanger body and provide a serpentine fluid flowing inside the tubes. A spherical cavity covered with glass plate placed in the exchanger received face, captures reflected rays. This glass plate creates a hot air room and reduces solar reflections rays. The back cover closes the heat exchanger and contains two openings inlet and outlet fluid. This exchanger offers a large heat transfer area and provides high heat transfer efficiency. The heat transfer fluid used is thermal oil.

The heat flux Q_u extracted by the heat exchanger is expressed as.

$$Q_u = \dot{m} C_{po} (T_{outlet} - T_{inlet}) \quad (6)$$

where $\dot{m}$ is the oil mass flow rate, C_{po} is the oil heat capacity and $(T_{outlet} - T_{inlet})$ is the temperature difference between inlet and outlet oil.

3. Thermodynamics analysis of SPC

The energy and exergy analysis was carried out to evaluate the system efficiency.

3.1. Energy analysis

The energy analysis is based on the first law of thermodynamics. The theoretical model employed for the study of the SPC is based on a thermal energy balance.

The solar absorbed energy Q_a by the receiver of solar parabolic dish system is given by [27]:

$$Q_a = G^* A_a \eta_{op} \quad (7)$$

where G^* , A_a and η_{op} are solar beam radiation, aperture area of dish concentrator and optical efficiency, respectively.

The approximated equation of the optical efficiency is written as.

$$\eta_{op} = \gamma \lambda \rho \tau \alpha \cos \theta \quad (8)$$

where λ , ρ and $\tau \alpha$ are the factor of un-shading, dish reflectance and transmittance-absorptance product, respectively. γ is the intercept factor of receiver which is defined as the ratio of the energy intercepted by the receiver to the energy reflected by the focusing device. θ is the incidence angle of solar beam into the dish which is equal to zero degree, therefore the Eq. (8) can be written as:

$$\eta_{op} = \gamma \lambda \rho \tau \alpha \quad (9)$$

The useful thermal energy Q_u can be determined as:

$$Q_u = Q_a - Q_p \quad (10)$$

$$Q_p = Q_{p,cv} + Q_{p,r} + Q_{p,cd} \quad (11)$$

Heat losses from a receiver Q_p occur due to the temperature difference between the receiver and its surroundings and depend on the geometry of the receiver and the collector. In this study, heat losses from the receivers are classified as conductive losses $Q_{p,cd}$, convective losses $Q_{p,cv}$ and radiative losses by surface emission from the inner surface of the receiver $Q_{p,r}$. Research has showed that the receiver conduction losses $Q_{p,cd}$ represent a small fraction of the receiver thermal losses [28]. In order to evaluate the conductive loss from receiver, the following equation is used [29].

$$Q_{p,cd} = [(1/(1/A_o h_w)) + (l/k_t(A_o A_w)^{1/2})](T_r - T_a) \quad (12)$$

To determine the outside convective heat transfer coefficient of wind h_w , the following correlations recommended by McAdams for the flow of air across a tube [30,31]:

$$\left\{ \begin{array}{ll} h_w D_o / k_{air} = 0.40 + 0.54 (V_w D_o / \nu_{air})^{0.52} & \text{for } 0.1 < V_w D_o (\nu_{air})^{-1} < 1000 \\ h_w D_o / k_{air} = 0.30 (V_w D_o / \nu_{air})^{0.6} & \text{for } 1000 < V_w D_o (\nu_{air})^{-1} < 50000 \end{array} \right\} \quad (13)$$

The convective losses in the receiver represent a significant fraction of the total losses in a dish system. Convective losses are a function of temperature, geometry, orientation, diameter of absorber, and wind velocity. Convection loss $Q_{p,cv}$ of the receiver system can be calculated using the Newton's Cooling Law.

$$Q_{p,cv} = h_{cv} A_c (T_r - T_a) \quad (14)$$

$$h_{cv} = h_n + h_f \quad (15)$$

Convection losses are greatest in the morning and become less significant during the middle of the day. Robert [30] subtracted the estimated forced convection losses from the total convective losses, given by the following equation:

$$h_f = 0.1967 V_w^{1.849} \quad (16)$$

$$h_n = \text{Nu}_{air} / d \quad (17)$$

Stine and McDonald performed natural convective heat loss experiments on the receiver [27]. This correlation is given in the following equation:

$$\text{Nu} = 0.088 \text{Gr}^{1/3} (T_r / T_a)^{0.18} (\cos \theta_z)^{2.47} (4.256 \times d/L)^s \quad (18)$$

where

$$\text{Gr} = g \beta (T_r - T_a) d^3 / \nu_{air}^2 \quad (19)$$

$$s = 1.12 - 0.982 (d/L) \quad (20)$$

The elevation angle θ_z is the angle between the line of sight to the sun and the vertical. It depends on the declination angle and the hour angle is determined by the following relationship [32]:

$$\cos \theta_z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega \quad (21)$$

The declination angle δ is the angular position of the sun at solar noon, with respect to the plane of the equator. The following expression of declination angle proposed by Cooper [32].

$$\delta = 23.45 \sin JD \quad (22)$$

$$JD = (n - 81)(360/365) \quad (23)$$

n is the date i.e. the number of days since 1 January.

The radiation losses in the receiver contribute to a significant fraction of the total losses in the receiver and in the total dish system. Unlike convection losses; radiation losses are relatively constant throughout the day once a steady-state temperature has been reached for the heater head temperature. Radiation losses Q_{rad} of the receiver system is given by:

$$Q_{rad} = Q_{rad}^r + Q_{rad}^e \quad (24)$$

The radiation losses due to reflectance Q_{rad}^r of the absorber surfaces depend of the receiver effective absorptance, and it is given by the following equation:

$$Q_{rad}^r = (1 - \alpha_{eff}) Q_a \quad (25)$$

The effective absorptance is given by the following equation [27]:

$$\alpha_{eff} = (\alpha_a / (\alpha_a + (1 - \alpha_a)(A_{ab}/A_c))) \quad (26)$$

The general equation for net radiation exchange [31,33] due to emission is given by the following equation:

$$Q_{rad}^e = \varepsilon_{eff} \sigma A_c (T_r^4 - T_a^4) \quad (27)$$

$$\varepsilon_{eff} = 1 / [1 + (1/(1 - \varepsilon_a))(A_{ab}/A_c)] \quad (28)$$

The thermal efficiency of the concentrator η_{en} based on the first law of thermodynamics is defined as the ratio between the useful energy and the direct solar radiation incident on the collector:

$$\eta_{en} = Q_u / I_h^* \quad (29)$$

The mean concentration factor of the system is giving by:

$$C_R = A_c Q_u / A_a I_h^* \quad (30)$$

where the direct solar radiation I_h^* is the difference between global radiation G^* and diffuse radiation D^* .

$$I_h^* = G^* - D^* \quad (31)$$

In order to determine the diffuse solar radiation D^* the following empirical correlation, as proposed by Stauter and Klein (1979) [32], is considered.

$$\frac{D^*}{G_c^*} = \begin{cases} 1.00 - 0.1k_c & \text{for } 0 < k_c < 0.48 \\ 1.11 + 0.039k_c - 0.789k_c^2 & \text{for } 0.48 < k_c < 1.1 \\ 0.2 & \text{for } k_c > 1.1 \end{cases} \quad (32)$$

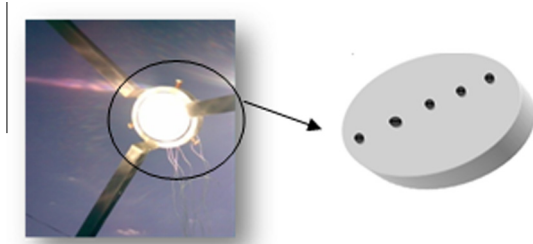


Fig. 1. Disk receiver.

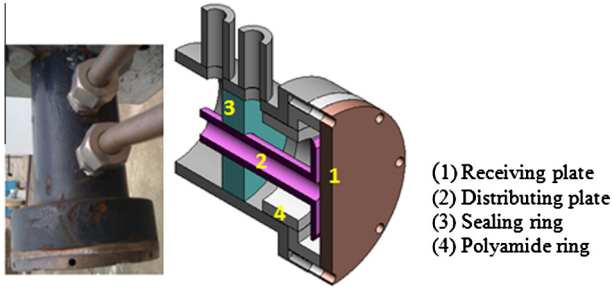


Fig. 2. The Cross-section of the calorimeter.

where

$$k_c = G^*/G_c^* \quad (33)$$

Diffuse, direct and global schedules irradiation for clear sky can be obtained by a simple integration [32]:

$$I_{hc}^* = E\tau_b \sin(\theta_z) \quad (34)$$

$$D_c^* = E\tau_d \sin(\theta_z) \quad (35)$$

$$G_c^* = I_{hc}^* + D_c^* \quad (36)$$

The power received outside the atmosphere E is equal to:

$$E = 1353(1 + 0.033 \cos((360/365)n)) \quad (37)$$

The atmosphere transparency of the direct radiation is giving by the formula presented by Hottel (1976) [32]:

$$\tau_b = r_0 a_0 + r_1 a_1 \exp(-r_k k / \sin \theta_z) \quad (38)$$

$$\tau_d = 0.2710 - 0.2939 \tau_b \quad (39)$$

where r_0 , r_1 and, r_k are constants depend on weather.

3.2. Exergy analysis

Exergy is a measure of the potential of the system to extract heat from the surroundings, as the system moves closer to the equilibrium with its environment [34,35].

The total exergetic solar power input to parabolic dish is given by [30,36]:

$$E_{xl} = G^* \left[1 - \frac{4}{3} (T_a/T_s) + \frac{1}{3} (T_a/T_s)^4 \right] \quad (40)$$

The temperature of the sun T_s is equal to 5600 K. The total exergetic absorbed by the receiver of the solar parabolic dish system is given by:

$$Ex_a = Q_a [1 - (T_a/T_r)] \quad (41)$$

The useful exergetic gain Ex_u can be determined by:

$$Ex_u = Q_u (1 - (T_a/T_r)) \quad (42)$$

The exergetic efficiency of SPC can be determined by:

$$\eta_{ex} = (Ex_u/Ex_l) \quad (43)$$

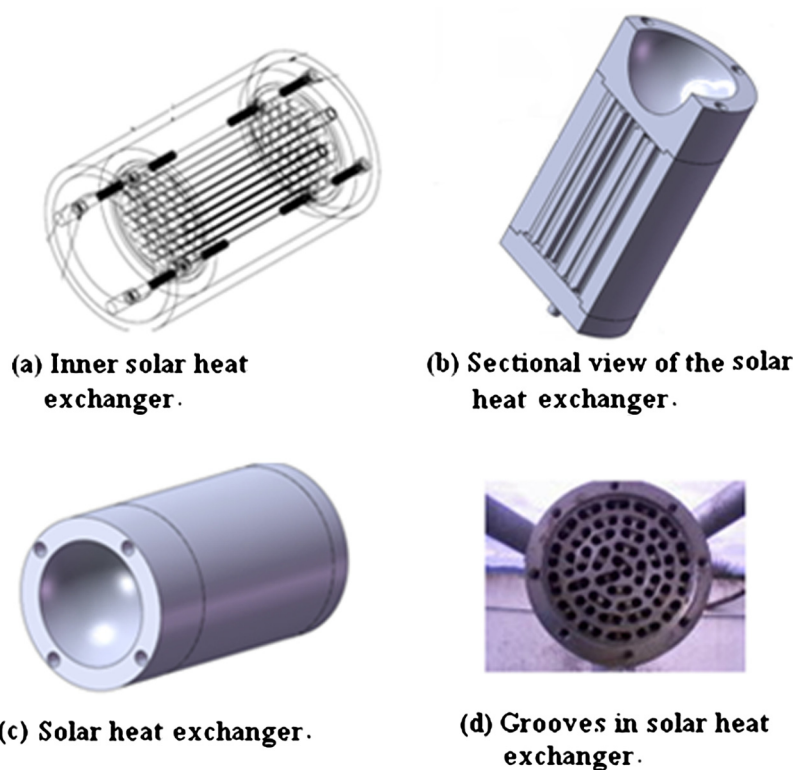


Fig. 3. The solar heat exchanger.

4. Experimental setup

The essential parts of experimental setup are the solar concentrating system, the receiver and instrumentation. The point focus solar concentrator consists of a dish with 3.8 m² of area, 2.2 m of opening diameter and 0.75 m of focal distance. The reflector is covered with a reflecting layer (solar mirror film) with an average reflectivity of 0.94. The temperature of the focal point varied between 300 °C and 900 °C depending upon weather conditions. The experimental device (Fig. 4) is equipped with two axes programmed solar tracking system and two motors. (See Figs. 5 and 6.)

Four experiences of SPC has been done using four receivers realized and tested in CRTEn: thin plate, disk, water calorimeter and solar heat exchanger in comparing days, respectively on the 23th of July 2012, 17th of August 2012, 20th of September 2012 and 30th of September 2012.

Experience 1: Five tests using thin plate method described in Section 2 has been done on the 23th of July 2012 for different instant in order to determine the absorbed solar energy. A k-thermocouple type placed in the plate center was channeled. In order to have more precision, we minimized the interval acquisition of results.

Experience 2: In this second experience, we tested the disk on the 17th of August 2012 where the main thermocouples used for this absorber are five K-type thermocouples (with ± 0.5 °C accuracy). They are placed in the internal face of the plate at 0.005 m depth. In Table 1 the radial locations of these thermocouples are reported. Two thermocouples are used for each symmetric radial position.

Experience 3: The water calorimeter is used as an absorber in this experience of the 20th of September 2012. Two instrumentations were arranged, the first is K-type thermocouples (with ± 0.5 °C accuracy) used to measure the difference between the outlet and inlet water temperature in the calorimeter (Fig. 2). The second determine the mass flow rate. This calorimeter is integrated in a hydraulic system composed of a water tank with 50 liters of volume, water pump and cooler. (See Fig. 1.)

Experience 4: Experimental study of the SHE is carried out on the 30th of September 2012 where similar to the WC, 2 K-type thermo-

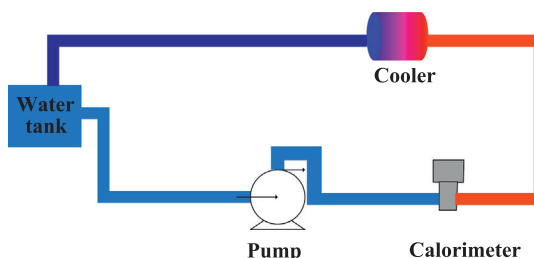


Fig. 5. The hydraulic circuit of WC experience.

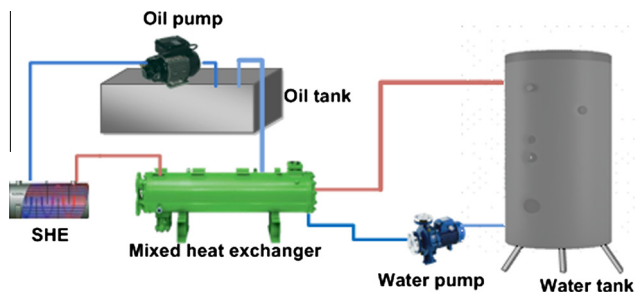


Fig. 6. The hydraulic circuit of SHE experience.

couples (with ± 0.5 °C accuracy) are used to determine inlet and outlet oil temperature (Fig. 3), and a fluxmeter to determine the mass flow rate. The hydraulic system using in this experience consists of a solar heat exchanger SHE, water tank, oil tank, water pump, mixed heat exchanger and oil pump.

Climatic conditions for those experiences are measured by a meteorological station on the site of Borj Cedria. It permits the measurement of the global solar radiation determined in the horizontal plane by Kipp and Zonen pyranometer (with $\pm 3\%$ accuracy), ambient temperature and wind speed. The acquisition was completed by an Agilent Technologies 34970A data acquisition system, with an HP34901A multiplexer card.

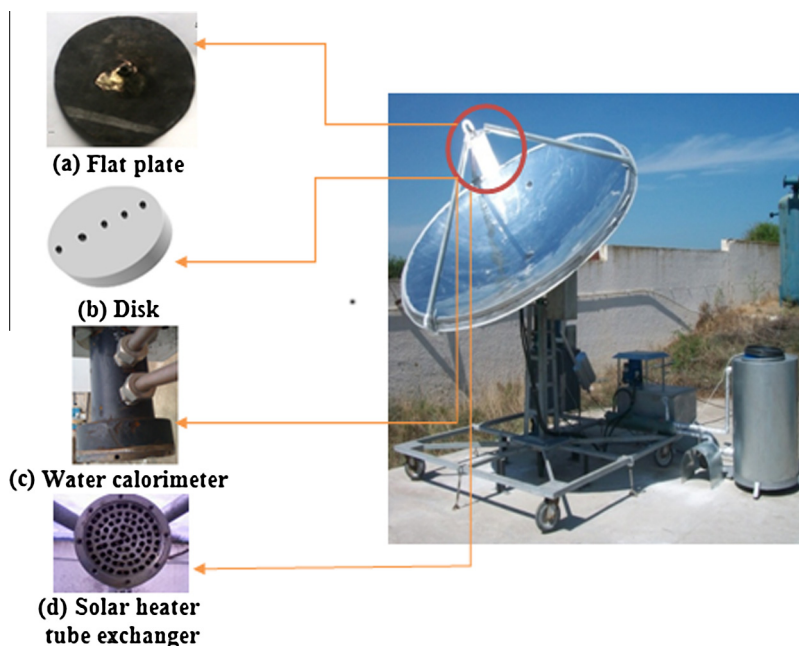


Fig. 4. The experimental setup using four receiver.

5. Results and discussion

5.1. The SPC performance using the thin plate

The global solar radiation, the direct received solar radiation, the useful energy, the thermal efficiency and the concentrated ratio for five tests of the SPC obtained using thin plate method are summarized in Table 2. In the beginning of the experiment, the temperature varied linearly with time. After 10 min from the starting acquisition, the thin plate temperature will be stabilized and attain a maximum value, 750 °C.

Therefore, to evaluate the average thermal efficiency and the concentrating factor, following equations Eqs. (29) and (30) are used respectively. The Experimental results of the thermal efficiency of the SPC are 57% and concentrating factor equal to 160, even as the severely solar radiation fluctuations and the wind effects.

The useful energy, determined by the equation Eq. (2), has an unvaried heat value roughly 1.2 kW after 12:58 pm (the second essay).

5.2. The SPC performance using the disk

The temporary temperature distribution along the disk at different positions is presented in Fig. 7. After 12:00, the P1, P2, P3, P4 and P5 temperatures (show Table 1) varied between 400 °C and 650 °C. Along the disk a symmetric distribution of temperature are shown, then the temperature at P1 and P5 positions have a comparative values around 600 °C. Also P2 and P4 symmetric positions relative to the center (P3) have a less temperature (400 °C).

The most temperature obtained by the receiver is on the center of the disk (P3). The maximum value of this temperature is around 650 °C that is very important with an average ambient temperature equal to 23 °C.

Table 2
Experimental results using thin plate receiver.

	Time (h)	G (w/m ²)	I (w/m ²)	Q_u (w)	η (%)	C_R
Test 1	11:14	1080.5	928.5	2160.6	61.23	219.81
Test 2	12:58	1103.2	543.1	869.8	41.9	145
Test 3	13:49	1020.8	517.1	1122.3	57	197
Test 4	14:30	949.6	650.2	1423.8	57.7	199
Test 5	14:58	877.4	600.3	1133.5	49.5	171

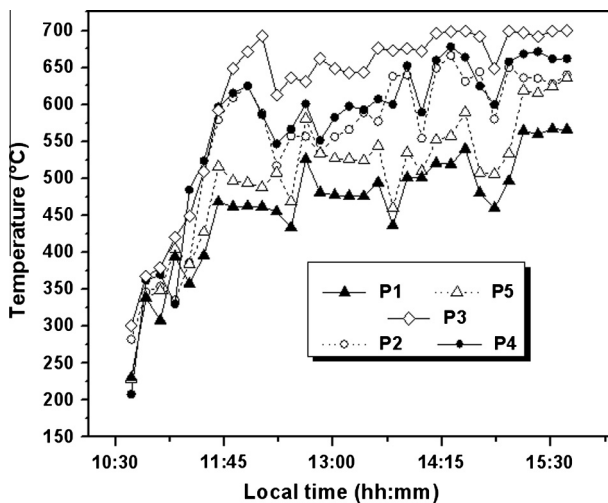


Fig. 7. Temporary temperature variation in different disk positions.

An analytical study based on a thermal energy balance described in the Section 3 used to determine the SPC thermal efficiency by Eq. (29). The average energy efficiency is equal to 70%. The various concentration ratios values, calculated by Eq. (30), are between 145 and 185 at the five positions (Fig. 8). Similar to the temperature distribution study, the concentration ratio presented a comparative values on the (P1 and P5) and (P2 and P4) positions.

Heat losses from the disk receiver are classified as conductive, convective and radiative losses. The overall heat losses occur due to the temperature difference between the receiver and its surroundings and depend on the geometry of the receiver and the collector.

The average heat losses from the disk in different positions are illustrated in Fig. 9. The convective heat losses, Eq. (14), towards the ambient are close to 15% and the radiative heat losses, Eq. (24), are close to 80%. It is clear that conduction losses are neglected in thermal balance and radiation losses are so important in concentration technologies.

5.3. The SPC performance using the water calorimeter as absorber

Experimental study of the solar water calorimeter is illustrated in Figs. 10 and 11. The figure (Fig. 10) presented the inlet and outlet water temperature of the calorimeter placed in the SPC focus under

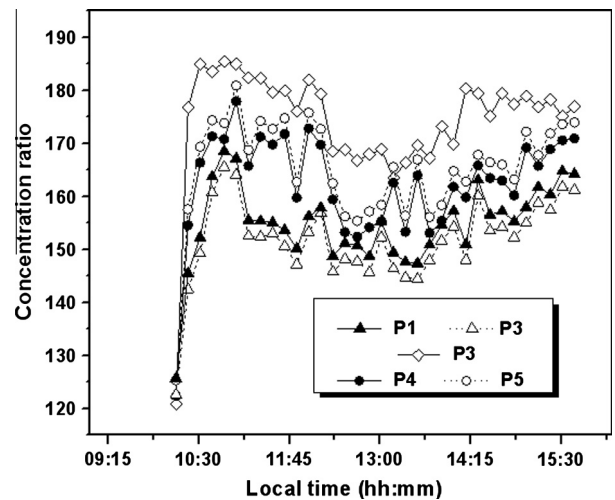


Fig. 8. Temporary variation of the SPC concentration ratio using the disk.

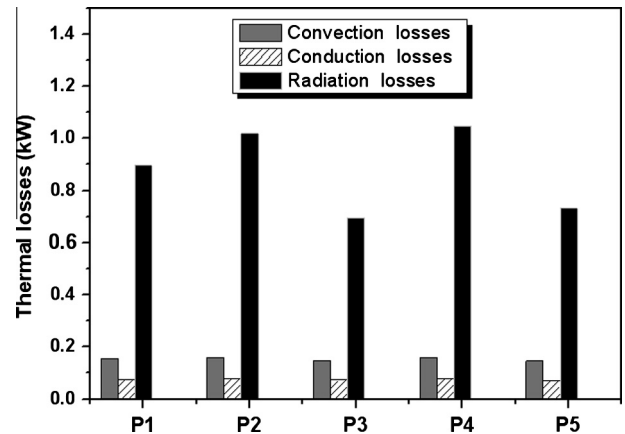


Fig. 9. Variation of the SPC thermal losses in five positions in the disk.

clear sky conditions and global solar radiation around 850 W m^{-2} . The outlet water temperature increase rapidly in the beginning of the experience, then it stabilized at a maximum value around 65°C for an ambient temperature 25°C and a fixed mass flow equal to 0.0192 kg/s . The mean difference between inlet and outlet temperature attain 30°C during the experience (6 h). So this calorimeter can be used to certain application requesting means temperature like water desalination, solar cooker. For a fewer mass flow rate used (outlet water temperature can achieve 100°C), steam production application can be take in.

The energy analysis of the SPC was performed with data obtained from the experiments. Fig. 11 shows the values of the instantaneous energy efficiency as function on 20 September 2012 using Eq. (29). The energy efficiency changed between 52% and 83%. The higher energy efficiency is obtained at noon. The average value of energy efficiency is about 72%.

The geometric ratio which is defined as the ratio of the aperture area of dish concentrator by the inner receiver area. The concentration ratio of the SPC depends to thermal efficiency and the geometric ratio. Using Eq. (30), the determined value of concentration factor reach 180.

5.4. Comparative thermal study of the SPC using SHE

In order to evaluate the experimental and analytical useful energy using SHE, Eqs. (6) and (10) have been respectively used. Fig. 12 has shown the analytical and experimental variation with time of the useful energy and global solar radiation using SHE.

For a peak solar radiation (3.8 kW), the optimum value of the experimental SHE useful energy was fluctuated between 1.8 kW and 2.2 kW along 3 h; this experimental fluctuation becomes from system tracking errors. The analytical results of the SHE useful energy are comparable maintained a constant values during a long period of this experience, is about 2.1 kW .

Experimental and analytical concentration ratio of the SPC using SHE has been shown in Fig. 13. The analytical concentration ratio using Eqs. (7)–(30) evaluated by the energy balance described in Section 3 is presented. The analytical average calculated value of the ratio is 178 and validated experimentally. The experimental concentration ratio of the SPC is determined by Eq. (30). The variations with time of the ratio revealed some fluctuations due to the solar tracking system, which adjusts by itself in time steps close to 4 s.

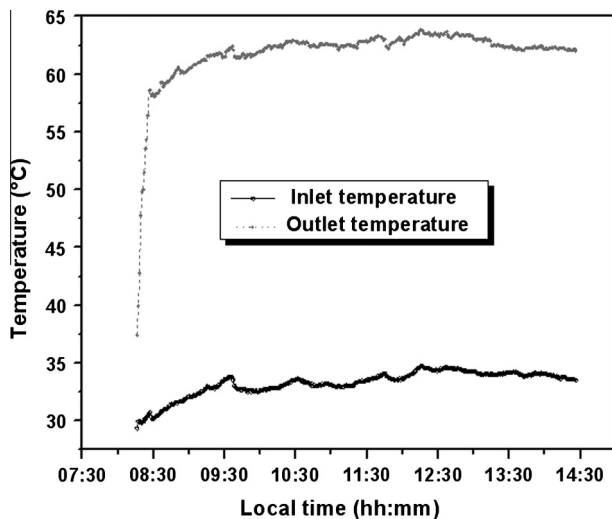


Fig. 10. Inlet and outlet water temperature of the calorimeter.

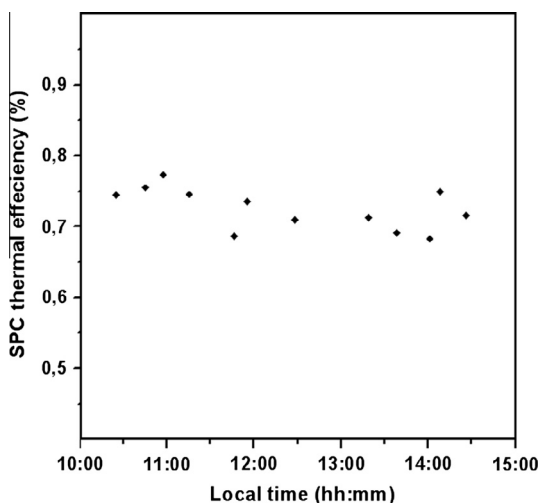


Fig. 11. Thermal SPC efficiency using water calorimeter.

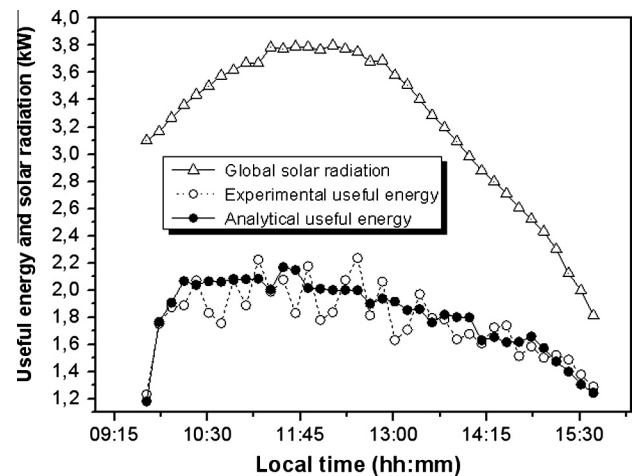


Fig. 12. Analytical and experimental variation with time of the useful energy and global solar radiation using SHE.

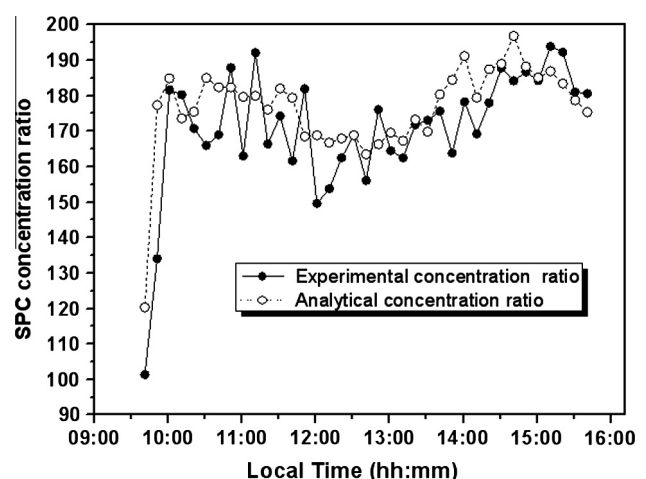


Fig. 13. Analytical and experimental variation with time of the SPC concentration ratio using SHE.

The energy and exergy efficiencies analysis of the SPC were performed with data obtained from the experiments using Eqs. (30) and (34). Figs. 14 and 15 shown experimental and analytical energy and exergy efficiency as function of time, respectively.

Therefore, the thermal energy efficiency, illustrated in Fig. 14, varied from 40% to 77%. We note a good agreement between the analytical and the experimental results. As compared with energetic efficiency, the exergetic efficiency is low; and it varied from 30% to 55% (Fig. 14). However, internal irreversibility is high when converting solar radiation in the form of thermal energy. Compared with the parabolic trough system, the efficiency SPC exergetic is more important, due to the higher receiver temperature 780 K.

6. Summary and interpretations

A comparative study has been done using four methods of absorbed solar flux measurements (thin plate, disk, water calorimeter and solar heat exchanger). The main findings of the present comparative study are summarized in Table 3.

Under comparative climatic condition for four days, with an average global solar radiation about 850 W m^{-2} and an average ambient temperature around 26°C , a constant value of the concentrating ratio is obtained using all measurements methods. The

Table 3

Recapitulative experimental results.

Receiver used	$G \text{ (W/m}^2\text{)}$	$T_a \text{ (}^\circ\text{C)}$	$Q_{th} \text{ (W)}$	C_R	$\eta_{en} \text{ (%)}$
Thin plate	950	27	1792	186	53
Disk	890	23	1649	180	70
Water calorimeter	850	25	1915	184	71
Solar heat exchanger	900	28	1852	180	72

average value of the ratio is 182. Also, the average SPC thermal efficiency is about 71% for last third methods except the thin plate method where less value efficiency seen, 53% and an average concentration ratio equal to 186 this difference it is due to the experimental error caused by the difficulty to assure the sudden change of temperature in order to eliminate any thermal changes with the outside.

A comparison between previous and current research are analyzed. Badran et al. [12] designed a portable solar cooker water heater, 150 cm in diameter; covered with aluminum foil the collector the average tank temperature is equal to 50°C . The maximum efficiency of the device in the water heating mode obtained was 77%.

A flat plate calorimeter was settled up by Jaramillo et al. [26] to evaluate measuring concentrated solar flux. They have shown that the radiative losses can be neglected in the thermal balance of the system. And they obtained a thermal efficiency around 86.3%.

7. Conclusion

An experimental study was conducted to the control of solar concentrating technologies using the four receivers: thin plate, disk, water calorimeter and solar heat exchanger. In this work we remark a good agreement between the analytical and the experimental results. The average concentration ratio and both average energy and exergy efficiency are respectively around 182, 71% and 55%.

The disk method necessities a thermal losses analysis is essentially to evaluate the useful energy. Flat plate calorimeter use water as a heat transfer fluid which can be vaporized for 100°C and this SPC devise can reach this value of temperature. So the solar heat exchanger can be a useful instrument to evaluate the thermal performance of point focus solar concentrating systems and that is suitable for other grater application.

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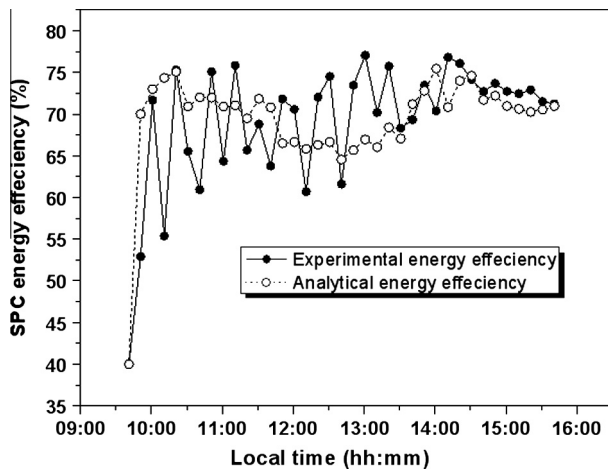


Fig. 14. Analytical and experimental variation with time of the SPC energy efficiency using SHE.

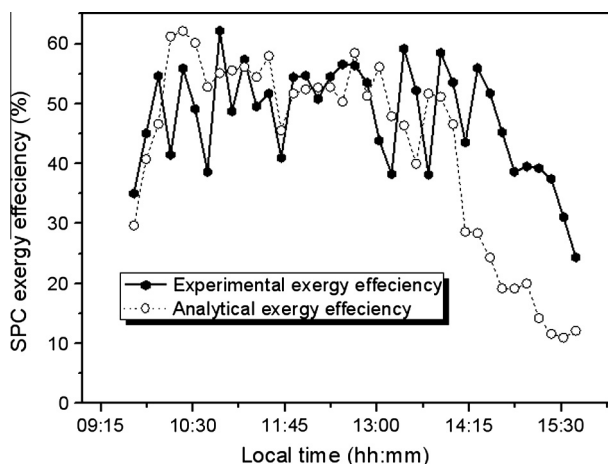


Fig. 15. Analytical and experimental variation with time of the SPC exergy efficiency using SHE.

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